RePlay® Agricultural Oil Seal and Preservation Agent

A Sustainable and Environmentally Safe Product for Effective Rejuvenation and Sealing of Asphalt Concrete Pavements

BIO-PAVE PRODUCTS LLC

BioSpan Technologies, Inc.
Making Science & Technology Practical™.

By

shatec
Engineering Consultants

SHATEC ENGINEERING CONSULTANTS, LLC
El Dorado Hills, California
www.shatec.net
916-990-6488

October 6, 2014

About the Author

Dr. Shakir Shatnawi is a registered professional engineer in California. He is a former California Department of Transportation (Caltrans) State Pavement Engineer and he is currently the president of Shatec Engineering Consultants, LLC where he directs the engineering operations, performs pavement studies/investigations and training. He has over 29 years in professional engineering experience encompassing public agencies (FHWA & Caltrans), academia and industry with over 200 technical publications.

Throughout his career, Dr. Shatnawi served as a principal investigator on multi-million dollar pavement projects. He was the QC/QA program manager, the chief of Pavement Research, the chief of Pavement Design and Rehabilitation and the chief of Pavement Preservation, and served as the Caltrans State Pavement Engineer. He directed Caltrans' Pavement Program as a Division Chief and oversaw over 50,000 lane miles with a budget of over $200 million in pavement preservation and over $500 million in pavement rehabilitation.

Shakir received his Ph.D. in civil engineering (Pavement Engineering specialty) from the University of Arkansas (1990), and received his M.S. in civil engineering (Construction Management specialty) from San Jose State University (1985), and B.S. degree in Civil Engineering from California State University, Sacramento (1982).

Dr. Shatnawi's education and experience demonstrate a wealth of engineering knowledge in pavement analysis, design, rehabilitation, materials and construction in asphalt, concrete, soils, earth structures and foundations. As an expert orator, Dr. Shatnawi frequently shares his knowledge at major conferences and through publications. As a recipient of many acknowledgements from the government and industry, Dr. Shatnawi has an impeccable reputation for his significant professional contributions. The following are some of his awards and acknowledgments:

- Received the Leadership in Transportation and Quality Pavements Award from the California Asphalt Pavement Association in 2010.
- Received the Industry Individual of the Year Award in 2008 for outstanding contributions to pavement preservation activities in California.
- Received the Caltrans Director's Superior Accomplishment Award in 2006 for outstanding accomplishments in pavement preservation.
- Received the Caltrans Director's Innovation Award in 2004 for outstanding contribution to pavement warranties.
- Received the Caltrans District 7 Excellence in Transportation Award in 2003 for outstanding contribution to the first long life rigid pavement project on I-10 near Pomona and the successful use of fast-setting hydraulic cement and dowel bar retrofit.
- Received the Industry Long Life Pavement Award of Excellence in 1999 for outstanding contribution to the 710 long life flexible pavement projects.
- Received the American Society of Civil Engineers' Award in 1999 for outstanding service as Education Chairman for the years 1997 through 1999.
- Received the FHWA Dwight Eisenhower Transportation Research Fellowship, 1989-1990.

Dr. Shatnawi's contact information:

Dr. Shakir Shatnawi, Ph.D., P.E., President
Shatec Engineering Consultants, LLC, 7064 Tarvisio Way, El Dorado Hill, CA 95762
Cell Phone: 916-990-6488, Office: 917-790-5811, Email: sshatnawi@shatec.net

White Paper on

RePlay®[1] Agricultural Oil Seal and Preservation Agent: *A Sustainable and Environmentally Safe Product for Effective Rejuvenation and Sealing of Asphalt Concrete Surfaced Pavements*

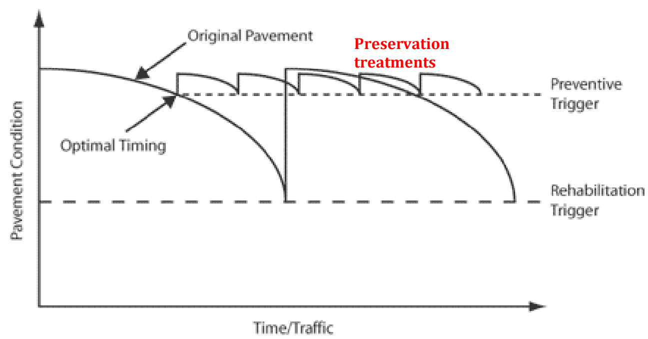
INTRODUCTION

Two categories of distresses affect asphalt concrete pavement: load-associated and non-load associated distresses (Huang 2003). The non-load associated distresses are exclusively contributed by the changes in the asphalt pavement temperature, moisture, and other climatic exposure including oxidation. Other factors that can contribute to this category of distresses include poor materials and construction practices. As the name implies, these distresses occur without the presence of traffic; though traffic loading can dramatically increase their severity. Age hardening of the asphalt concrete resulting from the oxidation of the asphalt binder is considered as a major cause and mechanism by which non-load related distresses develop. This is due to the associated increase in the binder's stiffness and viscosity due to hardening. Most common among non-load associated distresses are block cracking, longitudinal and transverse cracking, and raveling & weathering (Huang 2003). Block cracking is driven by volume change in HMA induced by daily temperature cycling and occurs over a large portion of the pavement area forming interconnected cracks that divide the pavement surface into nearly rectangular segments. Longitudinal cracks are parallel to the pavement's center line and usually occur due shrinkage of the HMA pavement caused by low temperatures or age-hardening of the asphalt binder (they may also occur due to reflection cracking from cracks beneath the asphalt course). Transverse cracks occur across the pavement width and are caused by low temperature or age hardening (they can also occur by reflection cracks). The last of non-load associated distresses is raveling and weathering caused by the wearing away of the pavement surface due to the dislodgement of aggregate particles and loss of asphalt binder. This distress is primarily caused by the age-hardening of the asphalt binder.

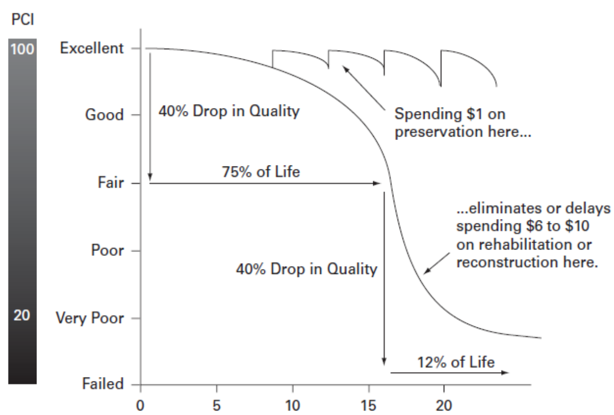
The most effective approach to avoiding the occurrence or minimizing the severity of non-load associated distresses in asphalt pavements is through establishing and aggressively funding a proactive pavement preservation program that employs common preventive maintenance activities including surface treatments, crack sealing, thin overlays, etc. A typical pavement preservation program engages in the application of the proper preventive maintenance treatments at the right times before damage becomes excessive. Therefore, an effective pavement preservation program takes preventive steps to protect the pavement assets before conditions deteriorate to levels warranting excessively costly repair. This is illustrated in Figure

[1] RePlay® Agricultural Oil Seal and Preservation Agent is a registered trademark of BioSpan Technologies, Inc., Washington, MO, USA.

1-a where a relatively inexpensive treatment applied to the pavement before condition deteriorates can extend the life of the pavement in as much the same way as a more serious and significantly costlier rehabilitation applied at a later time. Figure 1-b shows that a well-planned preservation program can result in substantial savings for the agency. For the example shown in Figure 1-b, spending $1 on pavement preservation treatment applied in the right time before the asphalt starts to deteriorate, can eliminate or postpone the need to spend 6-10 times or more the cost on serious and expensive rehabilitation or reconstruction.



(a)



(b)

Figure 1. Pavement preservation concept (a) Preservation versus rehabilitation, and (b) an example of saving that can be achieved by implementing a preservation program (Galehouse et al. 2006).

At early stages, non-load associated distresses can be effectively controlled through preservation or maintenance treatment. Oxidative age hardening of the asphalt binder is considered as the primary cause of non-load associated distresses. Therefore, pavement preservation treatments must be selected such that they are capable of delaying the aging process, reducing the pavement surface permeability to restrict the oxygen supply to the pavement, and protect the pavement from associated moisture damage. Relevant preservation treatments that seal the pavement surface against air and water intrusion include fog seals, topical pavement sealers, slurry seals, microsurfacing, ultrathin bonding wearing courses, chip seals, etc. (MTAG 2008). These treatments can vary greatly both in their effectiveness and cost depending on the existing pavement surface condition. At an early stage, topical seals such as fog seals can be both effective and low-cost. As the pavement surface condition deteriorates, more aggressive treatments become necessary.

In the remainder of this White Paper, the oxidative aging of the asphalt pavement and preservation/maintenance treatments to stop or reverse the oxidation damage of asphalt will be discussed. The effectiveness of RePlay®; a bio-based environmentally friendly rejuvenator and sealer is particularly presented in this paper.

OXIDATION DAMAGE OF ASPHALT

The oxidation of the asphalt binder (also called oxidative aging) in an asphalt concrete pavement is a major contributor to its premature failure. This is due to hardening of the asphalt concrete rendering it more susceptible to excessive fatigue cracking under repeated traffic loading. Ultraviolet (UV) radiation from the sun, as well as air and water are principal causes of asphalt oxidation.

Oxidation results in the damage of the asphalt bitumen; mainly the oily resinous component of the bitumen's hydrocarbon molecules, and the loss of its desirable characteristics. This starts to occur from the time the asphalt concrete is placed. The loss of the bitumen's desirable characteristics increases its viscosity and decreases its ductility resulting in hardening and embrittlement of the asphalt concrete. Cracks will start to occur in the asphalt concrete under traffic, allowing air and water into the asphalt and further deterioration of the bitumen characteristics. The presence of moisture in the voids of the mixture also increases its oxidation rate (Huang et al. 2007, Hanson et al. 2009). In the presence of moisture at the surface of the asphalt binder, the oxidation rate is estimated to increase by ~25% (Hanson et al. 2009). With hardening of the asphalt concrete, the fines are gradually lost from the mix leading to further deterioration or potential "shattering" of the pavement. Water penetrates even further into the pavement structure softening the lower unbound base and subbase materials and subgrade causing severe structural damage which may trigger the need for major pavement rehabilitation or reconstruction. It is obvious that a simple mechanism such as oxidation can result in excessive cost for pavement repair. Luckily, there are relatively inexpensive treatments and materials that can be employed as preventive maintenance measures to reduce or reverse the impact of oxidation on asphalt pavements in their early age of service (before irreversible damage occurs); thus overcoming the need for the substantially higher costs of rehabilitation repairs or reconstruction.

The hardening/stiffening (loss of ductility) of asphalt concrete due to oxidation reduces its important ability to react to inevitable temperature fluctuations. The rate of oxidation (age hardening) of the asphalt increases as the temperature in the pavement increases. Therefore, hardening is most severe at the pavement surface where temperatures are highest during summer. Besides temperature, the damaging

UV rays in the solar radiation catalyze oxidation of the asphalt binder resulting in additional hardening and damage to its ductile properties (Hanson et al. 2009). Mixture variables such as binder type (through its asphalt chemistry) and mix volumetrics can affect the oxidation rate. Some binders may oxidize at a faster rate than others, and water absorptive aggregates can result in greater loss of flexibility (ductility) of the binder used. The amount of interconnected voids in the asphalt mixture greatly affects oxygen and water movement (permeability) in the mix; thus influencing the hardening rate of the asphalt binder deep into the top lift.

With the reuse of oxidized asphalt pavement into new pavement, the oxidation issue is potentiated due to the pavement structural weakness caused by the introduction of the reclaimed asphalt pavement (RAP).

SURFACE TREATMENT

The oxidation of asphalt concrete is most severe in the first 2-4 years since placement (Kuennen 2006). As mentioned previously, oxidation aging occurs first at the pavement surface due to highest temperature occurring on the surface and exposure of the surface to the damaging effect of UV rays, water, and air. Therefore, in order to protect the pavement structure, this accelerated aging process must be confined to the pavement surface. This may be effectively achieved by the periodic application of sealers and rejuvenators; a preventive maintenance measure that is considered the most common and inexpensive method for halting, and sometime reversing, the oxidation process. Different types of materials have been used to different degrees of effectiveness; including emulsified sealers, asphalt binders, and especially formulated rejuvenators. Pavement rejuvenators are products especially designed to restore asphalt binder flexibility in an existing asphalt concrete pavement that has undergone the damaging effect of oxidation, while simultaneously stopping the loss of fines from the mix and sealing the surface against penetration by water, air, and chemical contaminants. Pavement rejuvenators are applied by spraying the rejuvenation material to the existing aged (or oxidized) asphalt pavement to restore asphalt concrete ductility besides improving other features. Therefore, the application of pavement rejuvenators can be an effective low-cost technology to slow or reverse the damaging effect of oxidation; thus extending the remaining service life of the pavement.

Most rejuvenators are formulated with oils that are selected to be capable of penetrating the asphalt pavement layer through its pore structure so as to improve the asphalt binder properties that were lost by oxidation. The oils used in formulating the rejuvenator must be selected or designed to replenish the oily fraction of the asphalt binder present in the mix. The most commonly used traditional emulsified sealers and asphalt binders are those that have been manufactured from petroleum products. In recent years, environmentally-friendly (green) rejuvenators and sealers have been introduced in the market and are currently finding wide acceptance worldwide as sustainable alternatives to traditional products. RePlay® is an agricultural oil seal and rejuvenation agent that has proved, both in the laboratory and field, to be a cost-effective and efficient preventive maintenance treatment for asphalt pavements since its introduction in the United State in 2003. The remainder of this white paper provides detailed information on benefits of using RePlay® as a green-technology rejuvenator and sealer in asphalt pavement maintenance. Detailed laboratory and field performance studies, and impact of using RePlay® on the environment are discussed.

RePlay®

Petroleum-based sealers and rejuvenators have traditionally been the standard materials attempted for preserving asphalt pavements against oxidative aging. Rejuvenators refer to the class of products designed to restore asphalt binder flexibility. Besides sealing the pavement, rejuvenators are capable (to variable degrees) of restoring the chemical properties lost by deterioration of the asphalt binder from the moment the asphalt concrete was placed. Therefore, an effective rejuvenator not only seals (against air, water and chemical contaminants) and penetrates the asphalt concrete, but also has the ability to chemically revitalize its asphalt binder through replacing lost oils with polymers to restore the binder's desirable properties that have been lost by oxidation.

In 2001, BioSpan Technologies, Inc. developed and patented a soybean-based sealant and rejuvenator product called RePlay® as a "green" alternative to petroleum-based topical sealants and rejuvenators, and was introduced to the United States market in 2003. RePlay® is 88% bio-based rejuvenator; of which 40% is derived from soybean oil (Kindler 2009). The remainder 12% of the RePlay® composition is recycled materials; particularly polystyrene, that is especially used in the formulation of RePlay® to impart essential polymers to the asphalt binder (Levy 2012). RePlay® rejuvenates the asphalt via reversing the oxidation process by adding new Superpave polymers; namely Styrene-Butadiene-Styrene (SBS) and Styrene-Butadiene-Butadiene-Styrene (SBBS)[2]; both effective in strengthening and increasing durability of the asphalt binder which improve the asphalt concrete resistance to raveling, rutting, and cracking. Five additional new polymers made from soy and other bio-based components further strengthen the asphalt binder material. Because RePlay® is petroleum-free product and made with recycled materials, it is both non-harmful to the environment and sustainable product, which also reduces dependence on and increasing prices of foreign oil. Whereas many petroleum-based rejuvenators may possess some of the attributes that RePlay® has, they are not ecologically-friendly and sustainable products, and may reduce the pavement surface skid resistance.

RePlay® BENEFITS

The use of RePlay® rejuvenator and oil sealer on asphalt concrete surfaced pavements offers myriad benefits that can be grouped into a number of areas pertaining to the pavement, environment, and users. Some of the benefits that have been reported in the literature include:

1. Renewing aged asphalt pavement that have hardened and became brittle.

[2] Patent pending

2. Softening the stiffness (hardness) of the oxidized asphalt pavement surface, making it less brittle, restoring its flexibility, slowing its rate of aging and oxidation, and extending its service life.
3. Sealing the disintegrated asphalt surfaces and halting further raveling and loss of fines from the aggregate matrix.
4. Sealing the pavement surface and hairline cracks; thus decreasing pavement permeability to water (by up to 95%).
5. Sealing the pavement against harmful chemical contaminants and deicing salt penetration.
6. Rejuvenating asphalt binder in asphalt mix by adding new SBS and SBBS, and 5 additional polymers (at least 15%).
7. Tightening and adding density to the existing asphalt binder; thus improving its resistance against UV damage.
8. Increasing the service life of a treated road surface by 2-3 times its untreated useful life span. A single application of RePlay® on the right pavement in the right time has been reported to add up to 5 years to the pavement service life.
9. Offering an inexpensive topical treatment method to extend pavement life and delay major maintenance and rehabilitation works. If RePlay® is applied in a preservation mode, an agency can achieve a long-term cost saving of several hundred percent compared to cost of traditional asphalt overlays.

Additionally, RePlay® offers the following advantages that are not typically offered by traditional petroleum-based rejuvenators and sealers:

10. It has low viscosity enabling it to flow easily into cracks and surface voids to seal them. It can penetrate a depth of 0.75” to 1.25” within the asphalt concrete layer in minutes.
11. It increases or at least maintains skid resistance of asphalt pavement.
12. It requires limited mobilization and construction time.
13. It does not have odor, or any oil tracking once cured.
14. It is safe around people, pets, and foliage.
15. It quickly absorbs, sets, and cures within 15-30 minutes after placement; thus reducing the duration of the lane or facility closure to traffic (vehicular and foot). It also does not require sand blotting; and as such it provides for lower maintenance costs.
16. It strongly bonds to asphalt matrix; thus no residual runoff or discharge may occur immediately after a rain or over time.
17. It is 88% agricultural-based, with 40% made from soybean oil; thus it is eco-friendly and completely non-toxic product.
18. It has a “carbon negative footprint”; thus it removes harmful greenhouse gases (GHG) in the surrounding environment.
19. It makes use of nanoparticle bio-based polymers to effectively attach to the binder.
20. It provides for a more aesthetically appealing pavement surface.

21. It is virtually clear and will not harm pavement delineation. No re-striping is necessary after application unless pavement striping is already deteriorated and needs to be replaced. Actually, it has been found to increase marking conspicuity and extend their service life. Also, while RePlay® slightly darkens lines, it does not alter the reflectivity of reflective beads.
22. Generally, it is not as temperature-sensitive as bitumen-based products; therefore, it can be applied nearly year-round.

RePlay® IS A GREEN TECHNOLOGY PRODUCT

Pavement agencies continue to strive to employ sustainable practices that reduce the stress on the environment. A number of programs (e.g., LEED and Greenroad) have been developed to rate and certify technologies used in the construction, preservation, maintenance, and rehabilitation of roadway and highway pavements in regard to their ability to provide for sustainable pavement solutions (Cleaver 2013).

RePlay® is considered a green asphalt preservation treatment, and the rejuvenation with RePlay® is considered a sustainable technology for reasons owing to both the rejuvenation process and the product, among which:

1. Rejuvenation process is relatively low-cost technology that revitalizes the existing pavement on-site without the need to remove and transport existing materials; thus minimizing traffic congestion and air pollution.
2. RePlay® as the rejuvenator agent and sealer is polymer-enhanced soybean oil (88% bio-based), and therefore an environmentally-friendly product. Most of the polymers in RePlay®'s formulation are derived from recycled material (polystyrene) coupled with the bio-based materials in the formulation.

The environmental impact of RePlay® from the point of its manufacturing to its application on pavement and eventual breakdown into the environment was assessed with BEES (Lippiatt 2011); a Building for Environmental and Economic Sustainability software developed by the US National Institute for Standards and Technology and uses the concepts of life cycle analysis, LCA (Levy 2012, BioSpan 2009). This study compared the environmental impact of RePlay® against a traditional petroleum-based alternative (Reclamite) emulsion made of specific petroleum oils and resins. The comparison considered all the stages in the life of the two products including (i) acquisition of raw material, (ii) manufacturing, (iii) transportation, (iv) installation, (v) use, and (vi) recycling and waste management (Levy 2012). The results of the analysis indicated that the petroleum-based product increased the amount of carbon dioxide (CO_2) in the environment; thus increasing the global warming potential, and required a greater amount of fuel energy during its life cycle compared to RePlay®. In fact, the use of the agricultural soybean-based RePlay® as a rejuvenator/sealer for asphalt concrete surfaced facilities was found to reduce the amount of CO_2 already present in the atmosphere because (i) no CO_2 is produced during manufacturing, and (ii) growing the agricultural material used in making the product (i.e., soybean plants) consumes CO_2 from the atmosphere. Figure 2 shows the equivalent amount of CO_2 produced and released to the environment during the life cycle of the two compared products in the various phases considered in the analysis. As shown in Figure 2, the amount of equivalent CO_2 added to the environment during the life cycle of Reclamite was over 1200 kg, whereas RePlay® removed about 400 kg of equivalent CO_2. Therefore, RePlay® has a carbon negative footprint. The amount of CO_2 depleted from the environment during the production of the agricultural material (soybeans) was found to easily offset the amount of CO_2 added during the manufacturing, transportation, and application of RePlay® (BioSpan 2009, Levy 2012). Additionally, raw material (soybean plant) returns nitrogen to the soil thus requiring less or no fertilizers (which are petroleum-based) to grow crops. Finally, because RePlay® is agricultural-based product (unlike petroleum-based products), it is safer to users during application.

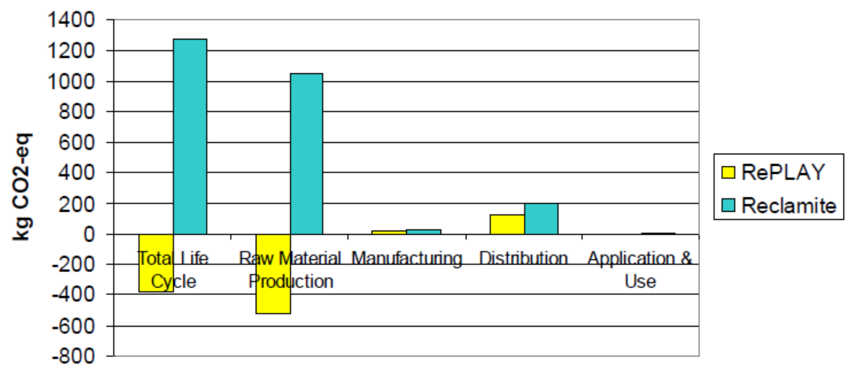


Figure 2. Global warming potential in terms of equivalent CO2 added or removed during all phase of production and use of RePlay® vs. Reclamite (from BioSpan 2008).

FIELD PERFORMANCE STUDIES

Skid Resistance

Skid resistance (in terms of friction number FN40) was measured on asphalt pavement sections on State Route 119 in Ohio between PM 2.70 and 3.05 (BioSpan 2010). Table 1shows results of testing before treatment (the top two sets of data) and at various times after application (19 and 69 minutes for eastbound direction and 28 and 60 minutes for the westbound direction). As can be seen in Table 1, skid numbers measured indicated that the application of RePlay® did not negatively impact skid resistance of the tested pavement surfaces.

Table 1. Skid resistance of state route 119 in Ohio before and after treatment with RePlay® (BioSpan 2010)

SKID TEST DATA

	RUN 1		RUN 2					
	LOG	SN	LOG	SN	MEAN	RANGE	MAX	MIN
Eastbound	2.79	46.5	2.80	47.1	46.8	0.6	47.1	46.5
	2.85	49.5	2.85	48.3	48.9	1.2	49.5	48.3
	2.91	44.9	2.90	44.2	44.5	0.7	44.9	44.2
	LOG	SN	LOG	SN	MEAN	RANGE	MAX	MIN
Westbound	2.82	41.8	2.81	46.3	44.1	4.4	46.3	41.8
	2.87	44.6	2.87	43.1	43.8	1.5	44.6	43.1
	2.94	44.2	2.95	45.0	44.6	0.8	45.0	44.2
	19 min. after		25 min. after					
	LOG	SN	LOG	SN	MEAN	RANGE	MAX	MIN
Eastbound	2.80	46.5	2.80	46.2	46.3	0.3	46.5	46.2
	2.86	41.1	2.86	44.4	42.7	3.2	44.4	41.1
	2.92	46.4	2.92	44.7	45.5	1.7	46.4	44.2
	69 min. after		75 min. after					
	LOG	SN	LOG	SN	MEAN	RANGE	MAX	MIN
	2.82	44.7	2.82	43.9	44.3	0.8	44.7	43.9
	2.87	42.4	2.87	43.3	42.9	0.8	43.3	42.4
	2.93	43.6	2.93	44.5	44.0	0.9	44.5	43.6
	28 min. after		33 min. after					
	LOG	SN	LOG	SN	MEAN	RANGE	MAX	MIN
Westbound	2.81	43.7	2.81	41.6	42.6	2.0	43.7	41.6
	2.88	35.7	2.89	37.8	36.7	2.1	37.8	35.7
	2.95	43.0	2.95	43.4	43.2	0.4	43.4	43.0
	60 min. after		70 min. after					
	LOG	SN	LOG	SN	MEAN	RANGE	MAX	MIN
	2.82	42.7	2.80	45.1	43.9	2.3	45.1	42.7
	2.88	43.9	2.88	40.1	42.0	3.7	43.9	40.1
	2.95	44.5	2.95	44.0	44.2	0.5	44.5	44.0

In a similar study in the State of New York in 2011 (NY State Thruway Authority), skid data in terms of friction number FN40 was collected on right, center, and left lanes of a two-mile section on a state Highway. The control data constitutes FN40 before application of RePlay® and two sets were also collected after RePlay® application: one on the same day of application after curing has completed, and the other set collected one week later. The maximum, minimum, average, and standard deviation of FN40 collected within the two-mile section are shown in Table 2. Inspection of the data reveals that the RePlay® application did not negatively affect skid data. Actually, skid resistance has improved with time to levels nearly similar or exceeding the original levels one week after application.

Table 2. Effect of RePlay® on skid resistance measured on a New York state highway (NY State Thruway Authority).

Lane	Statistic	Friction Number (FN40)		
		Before RePlay® 10/18/2011	After RePlay® 11/04/2011	After RePlay® 11/10/2011
Right lane	Max. FN40	46.2	45.5	47.2
	Min. FN40	42.8	38.3	40.3
	Avg. FN40	44.8	40.5	42.2
	Std. Dev. FN40	0.8	1.5	1.6
Center lane	Max. FN40	47.7	41.0	45.8
	Min. FN40	40.3	36.0	37.9
	Avg. FN40	44.5	38.9	41.6
	Std. Dev. FN40	2.2	1.2	1.8
Left lane	Max. FN40	50.3	52.3	53.4
	Min. FN40	45.6	45.8	48.8
	Avg. FN40	48.0	50.0	51.6
	Std. Dev. FN40	1.2	1.5	1.1

The Tyndall Air Force Base in Florida also conducted testing of skid resistance on runway pavements treated with RePlay® in comparison with skid of untreated sections (BioSpan 2014). The use of ecologically-friendly product such as RePlay® is important because airports are extremely environmentally sensitive due to the huge amount of jet fuels, vehicle exhausts, and electrical power and heating and cooling required; all combined exerting tremendous stress on the environment. Results of testing indicated that RePlay® did not significantly affect skid as treated sections did not demonstrate friction properties above the minimum action value (red threshold line) or even above the planning value (green threshold line) as shown in Figure 3.

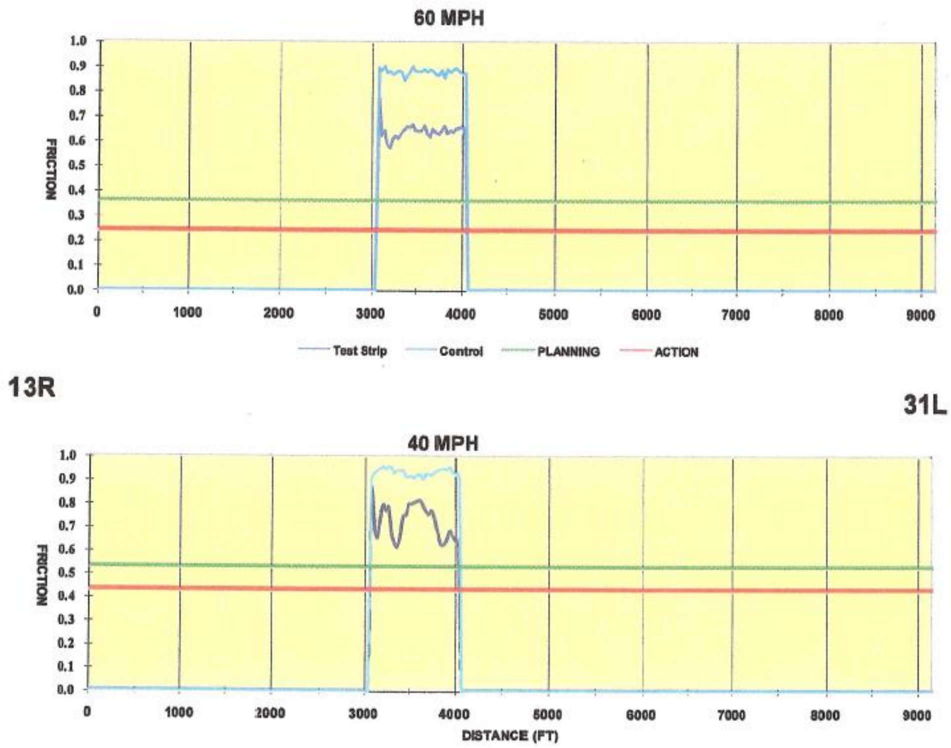


Figure 3. Friction tested on runways in Tyndall Air Force Base in Florida at 60 mph and 40 mph speeds.

Water Runoff

The City of Hutchinson conducted experiments on two asphalt paved surface to study the rate of water runoff (Olson 2011). This study was important because it is concerned with the safety of pedestrian's foot and bicycle traffic over wet surfaces following rain. One pavement test section was a 15-year old bicycle/pedestrian trail that has experienced raveling and cracking. The other section was a 5-year old paved driveway that did not show any major distresses on the surface except for some minor raveling. The experiment involved a RePlay®-treated section and a control (untreated) section in each pavement location. Water was poured onto all the pavement sections and the rate of runoff was visually observed. A significant difference was observed in the way water behaved on the trail and driveway pavement asphalt surfaces between the treated and untreated sections. Wicking was most notable in the untreated sections; higher wicking was observed in the older raveled trail pavement than the newer driveway asphalt surface. On the contrary, water ran off the treated sections at a high speed without wicking into the surface. Figure 4 shows photos of the experiment performed on the driveway pavement. Before treatment, water wicked into the surface as evidenced by the footprints and splash areas shown in Figure 4. Also, water ran off slowly toward the edges of the untreated pavement. The "after treatment" photos show that water ran off at a higher speed and the surface did not wick like it did prior to RePlay® application. Splash spots started to dry rather more quickly in the treated sections.

Visual inspection of pavements prior and after RePlay® application revealed RePlay® has sealed the asphalt surface. The treated pavements retained dark wet-looking appearance for ~2 weeks after application, after which the dark color started to fade slowly. After ~6 weeks, it was not possible to visibly distinguish treated surface from untreated surfaces (Olson 2011).

Before treatment with RePlay®

Before treatment with RePlay®

After treatment with RePlay®

After treatment with RePlay®

After treatment with RePlay®

After treatment with RePlay®

Figure 4. Runoff experiments on an asphalt driveway before and after treatment with RePlay® (Olson 2011).

This experiment concluded that the application of RePlay™ as a bio-based sealer is not only effective in sealing off the surface and removing water runoff quickly, but also safe to the environment. Unlike petroleum based sealers that are unsafe to the environment and inconvenient and undesirable for areas with high pedestrian traffic, RePlay™ is agricultural based product that cures (and traffic can be put back on the pavement) in less than 30 minutes, and can penetrate to replenish (rejuvenate) with essential Superpave polymers the top ¾” to 1 ¾” of the asphalt surface layer. The odor produced by RePlay® is similar to that of citrus degreaser, and not unpleasant making this product suitable for application in residential areas for sealing roads, driveways, parking areas, etc.

It has also been reported that water poured on a RePlay®-treated asphalt surface will bead on the surface aiding the drainage and fast removal of water off the surface (Surface Green 2014). Figure 5 shows two photos obtained from a different project (BPS 2014) depicting the fast runoff of water on an asphalt pavement treated with RePlay®.

Figure 5. Fast removal of runoff water on asphalt pavement surface treated with RePlay® (BPS 2014).

The use of RePlay® also offers other advantages to the environment compared to petroleum-based seals. This is related to the fact that petroleum-based seals do not cure completely and do not penetrate deep enough into the asphalt matrix, therefore run off can occur for several weeks after application. This will increase the risk of groundwater contamination, and can cause fish kill when runoffs enter water streams. In comparison, RePlay® is hydrophobic, and primarily agricultural-based product, thus it will not dissolve in water and non-toxic. Therefore, unlike petroleum-based products, RePlay® poses no risk to the groundwater or aquatic life.

LABORATORY STUDIES

Pavement Texture

ASTM E965 “The Sand Patch” or Volumetric Patch Test is the most commonly used method to measure pavement macro-texture or texture depth in pavement. The test consists of spreading out a known volume of standardized sand or small glass spheres over the pavement surface using a flat disk. The sand or glass spheres are distributed to form a circular patch. A small circle diameter indicates a high average texture depth; a larger circle diameter indicates a low average texture depth. The known volume of sand divided by the surface area covered by the sand (measured on site) yields the average texture depth. When comparing two samples (or locations) using this method, the results can effectively tell if a product has reduced the amount of voids in a surface.

In one study, the Sand Patch test was conducted on a number of samples extracted from two asphalt pavements from the City of Regina (Saskatchewan, Canada) before and after treatment with RePlay® (Massier 2010). The sand patch test measures the macro texture of the asphalt and allows for determining the mean texture depth (MTD). Results of testing indicated a reduction in MTD by 8% for one pavement surface and by 25% for the other. This indicates that the penetration of RePlay® into the surface pores has closed the surface significantly thus providing for a barrier to air, water, chemical contaminants, and de-icing salt intrusion into the voids within the pavement. Figure 6 shows a picture of one of the pavement surfaces tested before and after treatment with RePlay®.

In another study (KMS 2006), the Sand Patch test was performed on three pavements in Largo and Clearwater, Florida varying in their age both before treatment and 6 months after treatment with RePlay®. It was found that the MTD dropped by 19.5%, 24%, and 26%, respectively, for the 15-, 8-, and 3-year old pavements tested before and after the application of RePlay®. Figure 7 shows test locations and calculations for the three locations. The test results indicated that RePlay® helped fill voids in the tested asphalt pavements in a range from 19.5% to 26% thereby sealing out moisture, and reintroducing new polymers into those voids to add strength and flexibility, while maintaining skid resistance.

Figure 6. Surface texture of one of the asphalt pavements tested (Massier 2010).

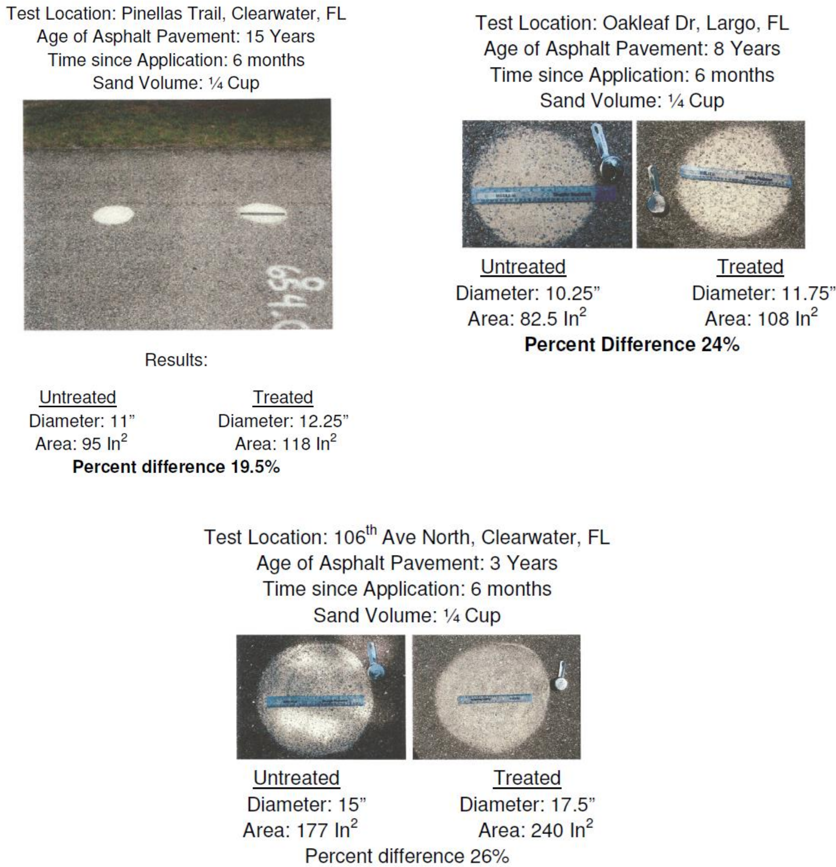


Figure 7. Sand Patch test results for three city streets in Florida.

Pavement Permeability

Besides conventional (dense) asphalt pavements, there are pervious asphalt pavements that are especially designed and constructed to drain quickly. Therefore, the use of bituminous seal coats on these pavements is not permitted which would otherwise force this type of pavement to lose its drainage capability. Unlike conventional sealers, RePlay® has significantly lower viscosity than normal asphalt sealers; therefore it is capable to penetrate deeper into the pervious pavement and rejuvenate and strengthen the binder with new polymers without clogging the internal porous structure of the pavement. Additionally, RePlay® is hydrophobic, so the internally RePlay®-coated porous structure within the asphalt concrete tends to repel the water that passes through draining it at a higher speed. Therefore, the water permeability increases by coating particles of the internal structure with RePlay® due to the significantly reduced tendency of water to absorb into the stone-binder matrix and the repulsion forces mobilized in the matrix.

Conventional (non-porous) pavements were also tested before and after treatment with RePlay®. RePlay® tends to fill voids on the asphalt concrete surface as was also evidenced from sand patch tests conducted on asphalt concrete surfaces to measure effect on texture, as discussed previously. Results of permeability testing of a set of treated and untreated asphalt concrete samples are shown in Table 3. As can be seen from Table 3, the permeability of treated asphalt concrete specimens has significantly dropped due to sealing the surface with RePlay® compared to untreated specimens.

Table 3. Permeability testing of RePlay®-treated and untreated conventional asphalt concrete samples (KMS and Associates).

		Untreated Samples			Treated Samples		
Specimen I.D.		I	II	III	4	5	6
Inside cross sectional of the buret, cm^2	a =	8.00	8.00	4.00	5.00	6.00	7.00
Average thickness of the test specimen, cm	L =	3.00	2.90	3.30	3.60	3.10	2.80
Average diameter of test specimen		15.20	15.20	15.20	15.20	15.20	15.20
Average cross-sectional area of test specimen, cm^2	A =	725.83	725.83	725.83	725.83	725.83	725.83
Elapsed time between h_1 and h_2, s	t =	60.0	31.0	900.0	343.0	900.0	900.0
Initial buret reading, mm		631.00	631.00	631.00	631.00	631.00	631.00
Final buret reading, mm		0.00	0.00	41.00	0.00	5.00	8.00
Initial head across the test specimen, cm	h_1 =	86.58	86.48	86.88	87.18	86.68	86.38
Final head across the test specimen, cm	h_2 =	23.48	23.38	27.88	24.08	24.08	24.08
Temperature of water, °C		25.0	25.0	25.0	25.0	25.0	25.0
Temperature correction for viscosity of water	t_c =	0.89	0.89	0.89	0.89	0.89	0.89
$k=(aL/At)\ln(h_1/h_2)t_c$							
Coefficient of Permeability ($x10^{-5}$ cm/s)**		**64**	**120**	**2**	**8**	**3**	**3**

Moisture Absorption

In an effort to experimentally examine the efficacy of RePlay® as a surface sealant to asphalt pavements, the City of Edmonton, Alberta, Canada conducted absorption testing in 2009 on a number of asphalt cores obtained from city street asphalt pavements (Donovan 2013). The purpose of the experiment was exactly to determine how RePlay® seals the asphalt concrete within the pore structures and along the microcracks. All cores were weighed and their density and air voids content determined using ASTM D 2726 and ASTM D 3203, respectively. All core samples were dried in a forced air oven at 40°C to a constant weight. Four core samples were then selected and surface-coated with RePlay® at the manufacturer recommended application rate. Two more cores samples were used as control without surface sealant applied. The treated core samples were allowed to cure for 1 hour before they were transferred to the water bath at room temperature and kept submerged, as shown in Figure 8. The control core samples were transferred into another water bath and kept submerged at room temperature. All core samples (treated and control) were weighed weekly (after gently drying their surfaces with absorptive towel), immediately returned to water bath, and then the amount and percentage of absorbed water were determined for each core sample. This process was continued until the cores weight remained constant indicating that the sample cores were fully saturated.

Figure 8. RePlay®-sealed core samples submerged in water at room temperature from Donovan 2013).

Figure 9 shows the water absorption percentage for all the core samples for a total of 1772 hours (73 days). As seen in Figure 9, there is a definite reduction in the amount of water absorbed into the sealed samples (lower curves) compared with the control samples (upper curves). The untreated samples absorbed as much as 10 times the amount of water absorbed by the samples treated with RePlay®. The reduction of water movement in the treated samples is desirable because it will reduce the damaging effect of water on the asphalt mix; thus extending the serviceability of the asphalt pavement.

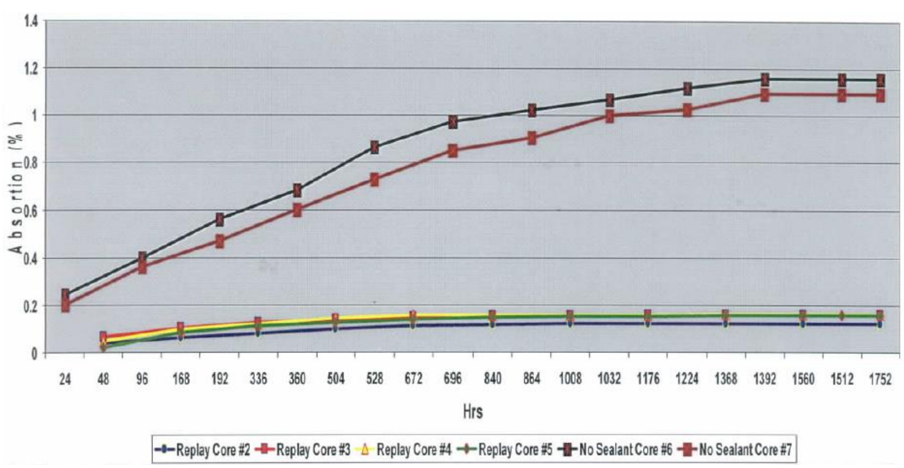


Figure 9. Water absorption into RePlay®-treated and untreated core samples (from Donovan 2013).

Polymers Penetration

FT-IR (Fourier transform-infrared) spectroscopy is a widely used technique for identifying chemical compounds in a product. In order to investigate the polymer permeation of the asphalt mixture when sealed with RePlay®, samples were obtained from the surface course of a PG 84-22 asphalt pavement from the state of New York and tested using FT-IR spectrometer (BioSpan Technologies, Inc.). Untreated samples were also tested with FT-IR spectrometer to examine the available air voids and to serve as control. Figure 10 shows images of both the control and RePlay®-penetrated samples along with their corresponding FT-IR scans. As can be seen in Figure 10, there is a noticeable difference in the FT-IR scans between the control and treated samples at ½” depth. The FT-IR scan of the treated sample demonstrates the penetration of polymers (both SBS and SBBS) from RePlay® at ½” depth as compared to the control scan. Quantitatively, RePlay® adds over 15% of new SBS and SBBS polymers to the asphalt binder in the mix. Successive FT-IR scans revealed polymers penetration to a depth from 0.75” to 1.25” into the mixture from the surface.

A description of the polymer permeation process of a PG 84-22 asphalt concrete samples at 1.25” depth along with 40x magnified images of the internal pore structure are shown in Figure 11 in comparison with a control sample.

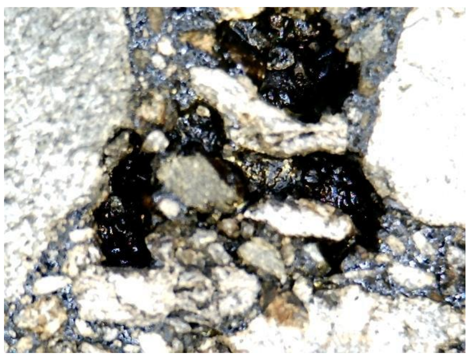
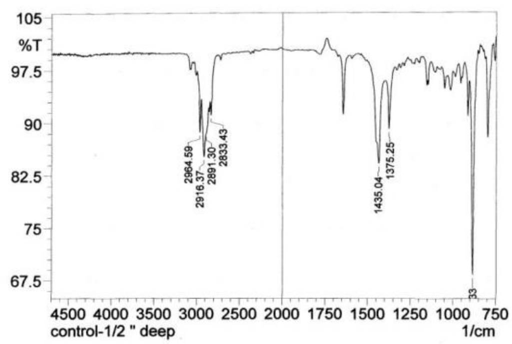


Image of control sample at ½” depth



FT-IR scan of control sample at ½” depth

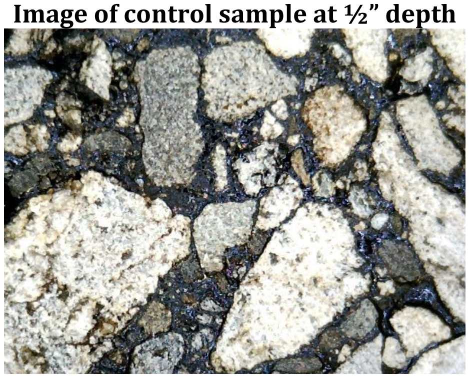
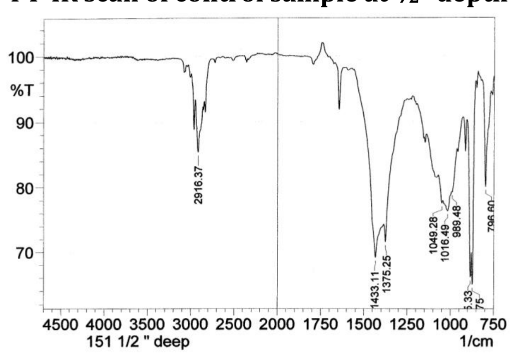


Image of treated sample at ½” depth



FT-IR scan of treated sample at ½” depth

Figure 10. Images at 40x magnification of the voids and FT-IR scan of both the control and treated samples at ½” depth (Cochran Engineering, Inc., Union, MO).

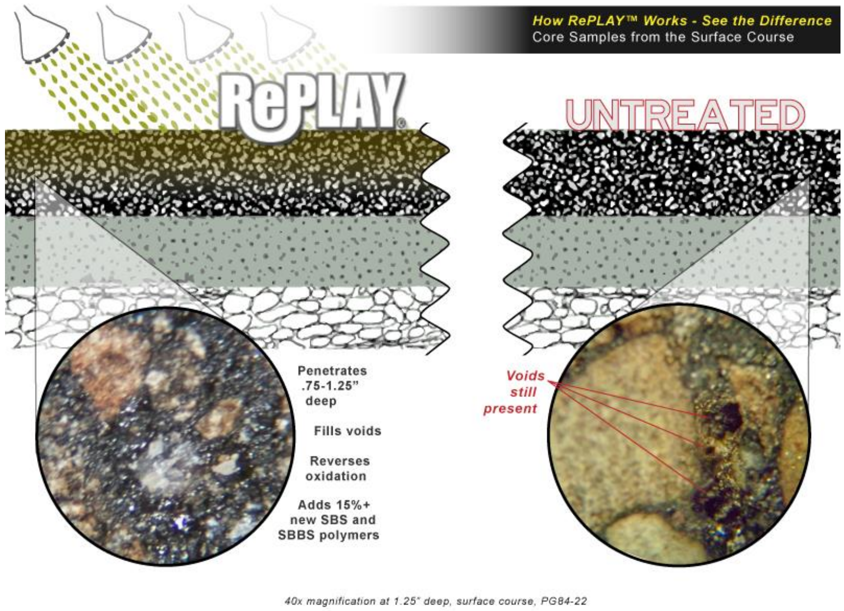
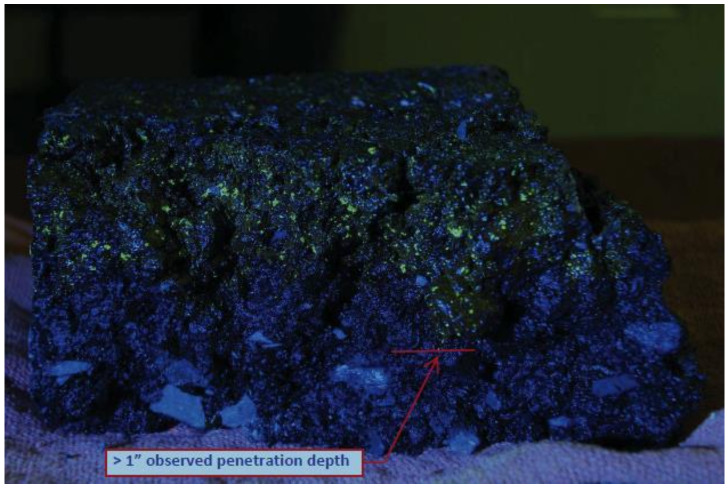


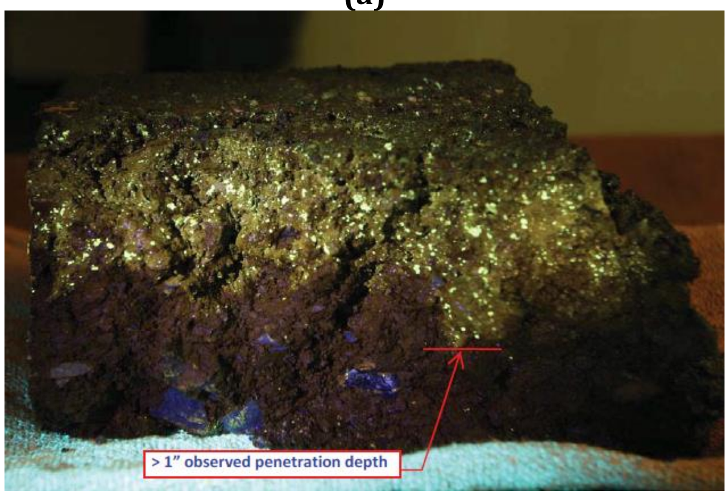
Figure 11. Polymer penetration with RePlay® of a PG 84-22 asphalt concrete sample at 1.25" depth compared to untreated sample (source BioSpan Technologies Inc. at http://biospantech.com/).

Visual Testing of Penetration

In a different study (BioPave Products 2014), the penetration depth of RePlay® into a number of asphalt concrete specimens treated with RePlay® at various application rates was visually inspected in a darkened room with the aid of bluelight and blacklight flashlights. Inspection of treated specimens revealed that the penetration of RePlay® into the asphalt samples was visually observed at least 1 inch below the surface, as can be noticed in one of the samples shown in Figure 12. Additionally, it was also concluded that penetration was deeper than what was visually observed as evidenced with the temporary softening of the asphalt mixture, smelling the citrus fragrance, and the presence of oil residue picked up on the fingers when the asphalt matrix was wiped below the visually observed penetration depth of 1 inch (BioPave Products 2014).



(a)



(b)

Figure 12. RePlay® penetration in one of the asphalt concrete samples as observed with the aid of: (a) bluelight flashlight, and (b) using blacklight flashlight (BioPave Products 2014).

Mechanical Properties

The effect of the soybean oil-based sealer and rejuvenator RePlay® treatment on the mechanical properties of asphalt concrete was investigated in a series of laboratory experiments on both treated and untreated (control) specimens cut out from cores obtained from actual in-service roadway asphalt pavements (CRRI 2010). The tests that were performed on the specimens included:

1. *Marshal stability test (ASTM D 1559)*: Stability and flow of core samples were measured at 60°C.
2. *Retained stability test (ASTM D 1075)*: This test measured stripping resistance of a asphalt concrete mixtures. Specimens were kept in water bath at 60°C for 24 hours and then tested for stability using the Marshal apparatus. Retained

stability is percentage of Marshal stability of saturated samples compared to stability determined in normal conditions.

3. *Tensile strength ratio (TSR) test (AASHTO T 283 and ASTM D4867)*: This test measures resistance of mixtures to moisture susceptibility. TSR is the ratio of indirect tensile strength (ITS) of wet specimen to that of dry of specimen.
4. *Moisture susceptibility:* The loss of adhesion of bitumen with the aggregate was studied by retained stability test and tensile strength ratio to examine effect of RePlay® treatment on resistance to moisture damage.
5. *Dynamic creep test:* This test was conducted by subjecting the samples to repeated axial loading comprised of a haversine wave with 100 kPa peak stress and 1 Hz frequency. The load was applied for 0.1 sec followed by 0.9 sec rest period. The accumulated strain and creep modulus were determined after applying a maximum of 3600 loading cycles.
6. *Binder recovery test (ASTM D2172 and ASTM D1856)*.

Table 4 summarizes the results of the various laboratory tests conducted on both the control and treated specimens. As Table 4 shows, the results of testing of both the core samples and recovered bitumen of untreated (control) and RePlay®-treated specimens indicate that the application of RePlay® improves the mechanical properties of the binder in the wearing surface of the roads.

Table 4. Mechanical properties of untreated and RePlay®-treated asphalt concrete specimens (data from CRRI 2010).

Test	Untreated (control)	RePlay® -treated	Change	Notes
Stability (kg)	924	1013	+9.6%	Improved strength due to treatment
Flow (mm)	2.9	3.1	+6.9%	Flow of modified samples is within acceptable range of 2-4 mm per the Asphalt Institute recommendations (Asphalt Institute 1979).
Dry ITS (kg/cm^2)	16.16	15.64	-3.2%	Slight decrease but not detrimental.
TSR (%)	64.24	81.65	+27.1%	Improved moisture susceptibility of modified samples.
Retained stability (%)	73.23	83.42	+13.9%	Improved retained stability due to treatment.
Accumulated strain at end of 3600 cycles (%)	0.71	0.60	-15.5%	Lower values of modified specimens indicate high resistance to permanent deformation.
Penetration of recovered bitumen (0.1 mm, 25^{o}C)	24	37		Result indicates improved performance of modified bitumen.
Softening point of recovered bitumen (^{o}C)	58	52		Result indicates improved performance of modified bitumen.
Ductility of recovered bitumen at 27^{o}C (cm)	33	47		Result indicates improved performance of modified bitumen.

CONSTRUCTION WITH RePlay®
General

RePlay® can be applied on any paved asphalt surface including asphalt parking lots, streets, highways, highway rumble strips, airport runways and taxiways, trails, sidewalks, and even tennis courts. RePlay®'s application is quite straightforward; but the following must be taken into consideration:

1. Pavement surfaces must be swept and cleaned prior to treatment to remove any standing water, dirt, leaves, foreign materials, etc. This work must be performed using hand-brooming, power-blowing, or other approved methods.
2. The surface texture of the pavement must be checked prior to application of rejuvenator to verify a good skid value. It is not advised to apply any type of rejuvenator for pavements with low skid resistance. If required, skid resistance testing must be performed prior to application of sealant.
3. The material must not be applied to wet or damp pavement surfaces. Do not apply during rainy or damp weather, or when rain is anticipated within 1-2 hrs after application. Pavement surface temperatures must be greater than 32^{o}F, and outside air temperatures must be 40^{o}F and rising.
4. It is best to apply RePlay® using special agricultural spray equipment suited for application of sealant and rejuvenation agents. A bituminous distributer can be modified to apply the agricultural bio-based oil sealant. A sprayer containing the product loaded into the back of a pickup or flatbed truck can also be used, as shown in Figure 13. A GPS system is sometimes used to ensure that the product is being applied precisely and uniformly over the surface. In almost all projects, only two workers will be required: one driver and another situated on the back of the truck to monitor the spraying equipment. Normally, one lane-mile of pavement requires ~2 hours to apply, and the pavement will be opened to traffic within 15-30 minutes after application. For smaller areas such as sidewalks, driveways, trail paths, etc. RePlay® can be applied with a hand-held sprayer as shown in Figure 13.

(a)

(b)

Figure 13. Application of RePlay® (a) with a sprayer with tank of RePlay® loaded on the back of pickup truck (BPS 2014) and (b) with hand-held sprayer connected to a RePlay® tank source (image taken from a video available on https://www.youtube.com/watch?v=xChuQa19D6I).

5. The rate of application of the RePlay® sealer depends on texture, porosity, and age of the asphalt pavement to be sealed. Application rate varies from 0.010 to 0.020 gallons per square yard (Surface Green 2014); and the average rate is 0.015 gallons per square yard.
6. Traffic must not be allowed on the roadway surface until RePlay® has penetrated the pavement surface and fully cured. Generally, this takes between 20 and 30 minutes with 50 to 80°F; but cooler temperatures will cause the cure time to increase.

Additional guidance regarding the proper application of RePlay® to pavements can be found elsewhere (Surface Green 2014).

Generic Specification

The following is a specification that can be used with projects involving the use of RePlay® (BioPave 2014):

General:

The Work in this section consists of furnishing materials and equipment necessary to perform all operations for the application of an asphalt rejuvenating agent to approximately 75 miles of asphalt concrete surface courses. The rejuvenation of surface courses shall be by spray application of an agriculture-based rejuvenating agent composed of soy oil derivatives and polymers. It shall be a Bio-based material with a minimum of 75% content.

Traffic:

Control of traffic in work zones shall be performed in conformity with this specification and *Roadway and Traffic Design Standards, 2002*, published by the Florida Department of Transportation (hereinafter referred to as the FDOT Standards), and with the requirements of the *Manual on Uniform Traffic Control Devices, Parts I and IV*.

Disruption to traffic flow must be held to a minimum amount of time. Traffic safety is the most important concern. Traffic must <u>not</u> be allowed onto roadway until materials have cured and skid numbers are back to acceptable standards (85-90% of original numbers, with documented proof of past projects available). Sand cover will not be permitted. The rejuvenating material shall not obscure or obstruct any traffic stripping or raised reflective pavement markings from functioning correctly.

Performance:

Rejuvenation product must have a proven life cycle extension of 3 to 5 years depending on traffic volumes.

Specifications for sealer and polymer binder:

Property	Requirement
Saybolt Viscosity at 77 F (25 C) ASTM D-244	5-20 Sec
Residue by distillation, or evaporation (3)	12% min and 18% max
Percent Volatile	N/A
pH	5.0-6.0
Solubility In Water	immiscible
Specific Gravity	0.8700-0.8800 (H_2O=1.0)
Boiling Point	310-330 Degrees F

Specifications for treated pavement:

Property	Requirement
Kinematic Viscosity ASTM D2170	20%INCREASE min.
Residual Polymer Test TX533C	4% INCREASE min
Asphalt Ignition Oven Report AASHTO T308 05	1- 2% INCREASE

Product description:

Sealant and preservation agent is a chemically engineered asphalt pavement sealer comprised of agricultural oils with polymers. It is designed to reverse the oxidation process as well as to give the pavement surface a water impermeable layer to prevent further oxidation. Moisture permeability is the principal cause of potholing and ultimate pavement deterioration. The sealant and preservation agent's unique chemistry penetrates into the asphalt matrix reducing the moisture penetration. The all-natural oils present help reverse asphalt oxidation in older asphalt pavements and prevent oxidation from occurring on new pavements. All asphalt mixes for parking lots, city streets, county roads, airport runways, airport taxiways, and airport parking aprons will be given improved impermeability as well as a reversal of some of the oxidation forces that have started. Due to the sealant and preservation agent's concentrated form it is applied in very light application rates with computerized spray equipment.

The sealant and preservation agent provides a seal without harming pavement stripping so restriping is not required and dries at the surface to allow traffic back on the pavement in less than 30 minutes but continues to work within the asphalt below for several weeks until the entire restorative process is complete. The sealant and preservation agent also places polymers into the asphalt binder, which will give the pavement a tougher surface more resistant to rutting, raveling, oxidation, and moisture penetration helping to prevent oxidation from re-occurring.

Application experience:

The asphalt sealant and rejuvenating agent shall be applied by an experienced applicator of such materials. The applicator shall have a minimum of 5 years experience in applying asphalt rejuvenators.

A project superintendent knowledgeable and experienced in application of the sealant and preservation agent must be in control of each day's work. The bidder shall submit a written experience outline of the project superintendent.

Application temperature/weather limitations:
The temperature of the sealant and preservation agent at the time of application shall be as recommended by the manufacturer. The sealant and preservation agent shall be applied only when the existing surface to be treated is thoroughly dry.

Handling of sealant and preservation agent:
Contents in totes shall be agitated before withdrawing any material for application. Cleanliness of the spreading equipment shall be subject to the approval and satisfaction of the Engineer. Each tote shall be accompanied by a FDA type certificate of analysis.

Application equipment:
Special agricultural spray equipment is probably best suited for application of the sealant and preservation agent.
The sealer and polymer binder can be applied using a specially adapted bituminous distributor that is properly modified to apply the agricultural sealant. Correct application rates would require unsafe speeds for standard unmodified asphalt distributors. The equipment must be in good working order and contain no contaminants or dilutants in the tank. Distributor bar tips must be the correct size and must be clean and free of burrs.

Any equipment, which is not maintained in full working order, or is proven inadequate to obtain the results prescribed, shall be repaired or replaced at the direction of the Engineer.

Application of sealer and polymer binder:
Rate of application shall be determined by the texture, porosity, and age of the asphalt pavement to be sealed. The rate of application can vary from 0.010 to 0.020 gallons per square yard. The average rate will generally be 0.015 gallons per square yard. The optimum application rate shall be determined by owner with the assistance of the contractor's experience.

The material shall not be applied to wet or damp pavement surfaces. Do not apply during rainy or damp weather, or when rain is anticipated within one to two hours after application is completed. Pavement surface temperatures shall be 32 degrees F (0 degrees C), and outside air temperatures shall be 40 degrees F (4 degrees C) and rising.

Traffic shall not be allowed on the roadway surface until the agricultural rejuvenator agent has penetrated and fully cured. Curing is generally 20-30 minutes with 50 to 80 degree F; cooler temperatures will cause the cure time to increase.

No sanding required:
The surface texture of the pavement to be sealed shall be checked prior to application of rejuvenator to verify a good skid value. A pavement with a poor skid value should not be treated with any type of rejuvenator. The sealant and preservation agent will approximately maintain the skid value of the pavement being treated but should not be used on a poor skid value in an attempt to improve its skid value with this product. Skid resistance testing shall be performed prior to application of sealant if there is a question.

Preparation and cleanup:
The Contractor shall be responsible for sweeping and cleaning of the streets prior to treatment, the street will be cleaned of all standing water, dirt, leaves, foreign materials, etc. This work shall be accomplished by hand-brooming, power-blowing, or other approved methods. If in the opinion of the Engineer the hand cleaning is not sufficient, then a self-propelled street sweeper shall be used. All turnouts, cul-de-sacs, etc., must be cleaned of any material to the satisfaction of the Engineer.

Description of work:
This work shall consist of controlling and maintaining traffic on rejuvenation application projects during the Contractor's operations in the roadway and of providing personnel and equipment for this purpose in accordance with these specifications and as the Public Works Department may require. The work shall include controlling access to the work zone from intersecting roads and adjoining property as may be prudent to ensure the safety of workers and the public and to protect the work and other property. Other traffic-related services may be required in the plans or elsewhere in the Contract.

Standards:
Control of traffic in work zones shall be performed in conformity with this specification and *Roadway and Traffic Design Standards, 2002*, published by the Florida Department of Transportation (hereinafter referred to as the FDOT Standards), and with the requirements of the *Manual on Uniform Traffic Control Devices, Parts I and IV.*

Traffic plan and authorization:
Prior to the start of work, the Contractor shall present a traffic plan to the Public Works Department for approval. In no case shall the Contractor place traffic control devices in the right-of-way, conduct rejuvenation application operations, or otherwise disrupt the normal flow of traffic without properly notifying the Public Works Department and receiving authorization.

Supervisor training.
The Contractor shall assign to the work site at least one employee who is certified as a Worksite Traffic Supervisor by the American Traffic Safety Services Association (ATSSA). A copy of the certificate will be included in the projects Traffic Plan.

Basis of payment:
Payment for the work shall be made at the contract prices or lump sum listed in the Bid Sheet. The contract prices shall be full payment for the work, including all incidental labor and materials necessary for completion of the work and not included in other pay items. Quantities of items to be paid on a unit price basis shall be as called for by the Public Works Department or prescribed in the traffic plan and as measured by the Public Works Inspector.

Unsatisfactory performance:
Substantial omissions or failure by the Contractor in providing the services specified herein shall be cause to immediately shut down the paving operation until the discrepancy or discrepancies have been corrected. The County shall not be liable for any loss the Contractor may incur for mobilization or wasted materials or for any other loss arising from the cessation of work.

Environmental stewardship:
All seals, rejuvenators, and asphalt preservation agents shall be free of harmful materials which will damage the environment during its application, and after it has been applied and is in use. The manufacturer shall certify that their product(s) used to stabilize and preserve the asphalt road surface shall not leach in the presence of moisture, rain, fog, or snow, and shall not contribute toxins or pollute the ground water runoff after its application. In case of a spill all products shall not harm or otherwise adversely affect the local flora adjacent to the road surface.

Health safety:
With concern for the general health, the MSDS sheet Health section shall assure that the carcinogenicity potential is None.

Substitutions:
The product " RePlay®" for the asphalt rejuvenating agent as manufactured by BioSpan Technologies, Inc. is the standard for these Specifications. The prices quoted on the proposal shall be for this standard. Should a bidder wish to submit a bid for an alternate to the Standard, said prices shall be entered on the proposal as "Alternate 1 ". In the event that the bidder submits no bid for the Standard, only the Alternate should be completed.

Bidders may propose an Alternate for the Standard product specified, provided the bidder adheres to the following and submits it with his bid:

1. This is a “Green” product made from soy oil derivatives, and 75% bio-based.
2. The pavement skid resistance shall be maintained because of the material penetrating into the pavement, not because abrasive material has been added.
3. List the proposed alternate on the bid sheet form giving the product name and price.
4. Furnish complete specifications and descriptive literature for the alternate as well as a 1-gallon sample of the asphalt rejuvenating agent proposed for use.

Such descriptive and detailed information shall be complete and at least equal in detail to the County's requirements for the standard item for which the alternate is offered.

5. Submit a current Material Safety Data Sheet for the alternate product(s).

PROPOSED FUTURE STUDIES

Although RePlay® has been around for only 11 years, significant amount of research in various important areas pertaining to its performance has been performed. Yet, additional research can highlight and validate many benefits and performance-related improvements that RePlay® was found to offer as a sealer and rejuvenator for asphalt paved surfaces from both field and laboratory-based research done so far. The following is some research areas that that may be considered:

1. Extraction of asphalt binder of treated and untreated samples at multiple depths below the treatment surface level and testing the effect of RePlay® on the binder's viscosity depth profile.
2. Field and laboratory aging of asphalt concrete subjected to RePlay® treatment in comparison with aging of untreated asphalt concrete specimens. Besides testing the effect of aging on viscosity of extracted binders, nondestructive testing of aged pavements in the field using falling weight deflectometer (FWD) followed by backcalculation analysis of resilient moduli, and testing dynamic modulus in the laboratory of aged specimens can provide valuable evidence as to the effect of RePlay® on aging performance.
3. Reflectivity testing on pavement markings at various times after application, and effect of RePlay® on nighttime visibility (glare).
4. Measuring temperature profile with depth within an existing asphalt pavement of treated and untreated asphalt surfaces. This study may verify the potential benefits of RePlay® on treated asphalt pavements in reflecting off heat and keeping the pavement cooler. Reduced temperature indicates reduced aging and maintained higher stiffness during hot days.
5. Laboratory testing of treated and untreated field core specimens to determine loss of aggregate and fines from the matrix. In the laboratory, this may be examined using pellet abrasion test that measure stability (and durability) of compacted specimen when dropped and rolled under standard conditions for specified duration.
6. Performing in-place permeability test before and after treatment with RePlay® initially and annually for the next 5 years after application, including testing a control section. The in-place permeability test can be performed using the air-induced field permeameter developed by the Kentucky Transportation Cabinet.
7. Conducting laboratory testing for moisture susceptibility of asphalt materials prepared in the laboratory and sealed with RePlay® in comparison with unsealed (control) samples. Test method AASHTO T283 may be used in conjunction with the application of freeze-thaw cycles to test resistance of treated samples to freeze-thaw damage.
8. Performing low-temperature testing of sealed and unsealed samples study resistance of RePlay®-treated asphalt concrete to low-temperature damage.

9. Conducting indirect tensile (IDT) testing of sealed and unsealed asphalt concrete specimens.
10. Bond strength testing of interface between newly placed asphalt concrete overlay over a RePlay®-sealed pavement surface. Specimens of sealed asphalt concrete of in-service pavements can be taken at various times after treatment (1 day, 6 months, 1 year) and then overlaid in the laboratory. The overlaid specimens will be tested with the pull-off test to evaluate bond strength.

SUMMARY

Oxidative aging of asphalt binders can result in the premature failure of flexible pavements. It starts at the time of construction and continues throughout the pavement's life. Oxidation of the asphalt binder causes major changes to the binder's properties, because these changes are detrimental to the desired performance of the asphalt concrete. This paper discussed the many factors that affect aging and the methods that are commonly used to halt or reverse the damaging effect of aging. Traditionally, petroleum (bituminous) based sealers and rejuvenators have been used with various degrees of success, but they all raise environmental concerns. Environmentally-friendly alternatives have recently been engineered, manufactured, and effectively used. RePlay® is a chemically engineered product comprised of soybean oil with recycled polymers that has been in use with great success as a sealer and rejuvenator of asphalt concrete surfaced facilities since 2003. RePlay® was designed to reverse oxidation and seal the pavement surface to prevent water and air intrusion that accelerates oxidation. RePlay® also makes use of recycled polystyrene to supply the essential SBS and SBBS polymers needed to rejuvenate the asphalt binder to improve the pavement resistance to raveling, rutting, and cracking. When used in preventive maintenance mode, RePlay® can add five years to the service life with each application. Besides, unlike petroleum-based products, RePlay® is non-toxic, non-polluting, safe for both the users and construction workers, environmentally friendly, and not affected by increasing the price in oil. This paper discussed the many benefits offered by RePlay® that improve the performance of asphalt paved surface, including its impact on the environment as a sustainable alternative to traditional petroleum based products. RePlay® has been shown to be not only environmentally safe, but a product that has a negative carbon footprint that helps in reducing the amount of hazardous greenhouse gases present in the atmosphere.

In conclusion, the use of the agricultural-based rejuvenator and sealer RePlay® offers an effective alternative to using petroleum-based products from both economical and environmental standpoints.

REFERENCES

Asphalt Institute (1979). Mix design methods for asphalt concrete and other hot-mix types. Manual Series No. 2 (MS-2). Asphalt Institute. Lexington, KY.

BioPave (2014). Generic specification. BioPave Products LLC. This specification can be found at http://bio-paveproducts.com/wp-content/uploads/2014/06/Bio-Pave-RePLAY-Brochure-2014-0612.pdf

Bio Protection Solution (2014). RePlay® Agricultural oil seal and preservation agent. This can be found at http://bioprotectionsolutions.com/products/asphalt-solutions/replay

BioSpan (2008). LCA BEES Analysis: RePlay® agricultural oil seal and preservation agent vs. a petroleum-based alternative product. Summary report. BioSpan Technologies, Inc. Four Elements Consulting, LLC & Omni Tech International, 17 p.

BioSpan Technologies, Inc. (2009). Life cycle assessment. This can be found at http://biospantech.com/life-cycle-assessment/

BioSpan (2010). RePlay® agricultural oil seal and preservation agent. BioSpan Technologies, Inc. Brochure. This brochure can be found at http://replay.biospantech.com/wp-content/uploads/2010/04/RePLAY_skidtest.pdf

BioSpan (2014). BioSpan Technologies, Inc. http://replay.biospantech.com/air-force-tests-replay-on-runways

Cleaver L. (2013). How to make a greenroad. Asphalt Contractor Magazine, October 29, 2013. Article can be found at http://www.forconstructionpros.com/article/11213946/how-to-make-a-greenroad

CRRI (2010). Laboratory and field evaluation of RePlay® (a soya bean based asphalt polymer). Final Report. Central Road Research Institute, Flexible Pavement Division, New Delhi, India. The report can be found at http://biospantech.com/wp-content/uploads/2010/06/RePLAY-CRRI-June2010.pdf

Donovan H. 2013. Evaluation of RePlay®, Engineering Services Center, City of Edmonton, Alberta, Canada.

Galehouse L., Moulthrop J. S., and Hicks R. G. FHWA (2006). Principles of pavement preservation: definitions, benefits, issues, and barriers. In Pavement Preservation Compendium II, Pages 67-73. Federal Highway Administration (FHWA). This can be found at http://www.fhwa.dot.gov/pavement/preservation/ppc0621.cfm

Hanson D.I., King G., Buncher M., Duval J., Blankenship P., Anderson M. (2009). Techniques for prevention and remediation of non-load related distresses on HMA airport pavements (Phase I). Airfield Asphalt Pavement Technology Program (AAPTP), Federal Aviation Administration (FAA), Final Report, 125 p. The report can be found at http://www.aaptp.us/Report.Final.05-07.pdf

Huang S.C., Turner T.F., and Thomas K. P. (2007). The influence of moisture on the aging characteristics of bitumen. 4th Eurasphalt & Eurobitume Congress.

Huang Y. H. (2003). Pavement analysis and design. Prentice-Hall, Englewood Cliffs, New Jersey.

Kindler, J. (2009). Soybeans are extending the life of Ohio roadways. Ohio Soybean Review, Spring edition, p. 21.

KMS (2006). ASTM E 965-Sand Patch Test. Report. KMS and Associates, Inc. Report.

Kuennen T. (2006). Pavement preservation: Techniques for making roads last. In pavement Preservation Compendium II, Pages 12-14. Federal Highway Administration (FHWA). This paper can be found at http://www.fhwa.dot.gov/pavement/preservation/ppc06.pdf

Levy P. (2012). RePlay®: Green technology for the future. This report can be found at http://www.surfacegreen.ca/Files/paullevytechnicalreport_RePLAY.pdf

Lippiatt, B. (2011). Software BEES. Retrieved from National Institute for Standards and Technology: http://www.nist.gov/el/economics/BEESSoftware.cfm

Massier D. (2010). RePlay® agricultural oil seal and preservation agent. Report. City of Regina, Saskatchewan, Canada. Report can be found at http://www.surfacegreen.ca/Files/regina.pdf

MTAG (2008). Maintenance technical advisory guide. Volume I: Flexible Pavements. California Department of Transportation. Second Edition. 354 pages. This guide can be found at http://www.dot.ca.gov/hq/esc/oe/project_ads_addenda/04/04-1637U4/Reference%20Documents/Operations%20and%20Maintenance/Maintenance%20Technical%20Advisory%20Guide%20-%20Volume%20I%20-%20Flexible%20Pavement%20Preservation.pdf

Olson J. (2011). Application of RePlay® agricultural oil seal and preservation agent. City of Hutchinson, McLeod County. Project No. 2010-15.

Surface Green (2014). RePlay® asphalt rejuvenating surface treatment technical data manual. Surface Green Solutions, Inc., 9 pages. This manual can be found at http://www.surfacegreen.ca/Files/replaytechnicaldatamanual.pdf

End of Text